Relay Contact Behavior Under Non-Eroding Circuit Conditions

By H. J. KEEFER and R. H. GUMLEY

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When palladium or platinum-family metal contacts are operated in an environment which includes organic vapors, the performance of the contacts may be seriously degraded. If the contacts open and close currents, the contact erosion may be increased enormously. On the other hand, if the contacts merely prepare the circuit and do not directly open or close the current flow, no erosion will take place. The contacts may then fail to conduct the circuit current satisfactorily, because of the formation of an insulating polymer-like film. This latter type of failure has been the subject of extensive studies at Bell Telephone Laboratories for the past several years and is the subject of this article. These studies have yielded a new understanding of the contact problem and resulted in certain changes in relay contacts to improve their performance under service conditions.

I. HISTORICAL

The effect of organic vapors in degrading the performance of platinum metal relay contacts has long been recognized. In a paper published in 1927 by E. A. Watson,[1] it was shown that carbon readily deposits as a closely adherent film on the contact surfaces, increasing the tendency of the contacts to arc and greatly accelerating the electrical erosion. An early investigation into the effect of organic vapors in enhancing contact erosion is described by A. Brooks in a discussion of a paper by J. C. Chaston.[2]

Prior to the introduction of the No. 1 crossbar system in the late 1930's, the effect of organic vapors on relay contacts was not of great concern in Bell System equipments. Dust was considered to be the main cause of contact failure, the requirements for contact reliability were not as exacting and automatic means for detection of contact failure were not as commonly employed. Except for some unusual effects that

occurred at the time some laboratory rooms were painted, the effect of organic vapors on relay contacts attracted little interest.

Toward the end of the 1930's, the No. 1 crossbar local switching system was developed. This system and all subsequent crossbar systems were of the common control type, using markers that put increasing demands on the operating speed, life and reliability of the relays. The relay contacts had to operate faster and more often, switch larger currents and last longer. With the No. 1 crossbar system came the U-type relay using cellulose-acetate-filled coils that increased the quantity of organic vapors. However, the effect of these vapors on the contact performance was not immediately apparent.

In 1943, an attempt was made in the Switching Systems laboratory to increase contact reliability of U-type relays by enclosing the relays in sealed containers for dust exclusion. It was found, however, that the erosion of the relay contacts was increased 20 times or more, because of the increased concentration of organic vapors. A series of tests was initiated to explore this effect, and a summary of some of the effects has been published.[3] Simultaneously and independently, the Telegraph Development Department laboratory was finding that new organic materials incorporated into the 255-type telegraph relay had greatly accelerated the erosion of the relay contacts. In 1948, contact erosion tests on the prototype of the wire-spring relay indicated the need for a contact cover that did not enclose the coil. This contact cover is a feature of all wire-spring relays now used in switching systems. Since the war, the effect of organic vapors in accelerating contact erosion has been intensively studied by L. H. Germer and his associates at the Laboratories.[4]

During this time, it was known that the deposits from the organic vapors could cause some contact resistance, but this was considered to be a much less serious fault than the erosion effect. In 1948, an analysis by means of the replica technique[5] of failing contacts in service, disclosed that a polymer-like* type of deposit was formed on palladium contacts, particularly on those contacts that were not subject to electrical erosion. A replica taken from an AF relay contact showing the polymer formation is illustrated in Fig. 1. The highly insulating properties of this material indicated a previously unknown cause of contact failure, but the importance of the discovery could not be estimated until large-

* The mechanism of generation of this insulating material is not completely understood. For the purposes of this paper it is necessary to distinguish between this insulating material and other organic deposits such as the carbonaceous deposits that result when contacts are in the presence of organic vapors. Since this insulating material has many of the attributes of a polymer it will be referred to as such.

Fig. 1 — Replica of an AF relay twin palladium contact, showing polymer formation at the contact area. (Magnification 40 times.)

scale relay operating tests were made. Nevertheless, an investigation into the physics and chemistry of this organic deposit was immediately started. Results are contained in a companion article.[6]

In 1951, tests were made in the laboratory on a large number of U-type relays in various types of dust enclosures. Results showed that the failures caused by polymer were more numerous than the dust failures.[7] Nevertheless, it was felt that the U-type relay had fairly good contact reliability in telephone service and, since dust appeared to be the main trouble under service conditions, no change involving increased costs could be justified to reduce the polymer contamination of the contacts.

In 1951, it was found that certain contacts carrying talking currents had become microphonic and under some conditions noisy in service. Investigation showed the noise to be due to polymer and carbonaceous deposits on the contacts which, when vibrated by the operation of adjacent relays, generated the noise.

In 1953, large-scale contact-reliability tests on pre-production wire-spring relays were started. In these tests, the wire-spring relay was found to have a higher failure rate from polymer contamination than did the U-type relay. To avoid risk of potential service difficulties, a

1-mil 22-karat gold overlay was specified over the 9-mil palladium contacts on wire-spring relays, because only a trace of the polymer forms on gold. For economy, the standard wire-spring relay design uses the gold overlay only on the moving contacts. Laboratory tests have shown that this compromise is satisfactory and that the relay, so equipped, will outperform the U-type relay equipped with palladium contacts, from an open-contact standpoint.

In 1955, open-contact failures were experienced in service with palladium contacts of digit-absorbing selectors of the step-by-step system. These failures were particularly serious, since they were of the type that deny service to the customer. The contacts were changed to Western Electric No. 1 metal,* since this contact metal was known to give substantially improved performance and could be made available quickly. No further difficulty has been experienced from these contacts.

The laboratory studies to date have indicated that gold, silver or their alloys are the best solution to the polymer problem. The use of an alloy of high gold content is preferred because of the undesirable sulphiding characteristics of silver. The gold overlay used on the wire-spring relays is 22-karat gold, the 8 per cent silver content being solely for hardening purposes. The gold-overlay-on-palladium contact is preferred to a solid gold-alloy contact such as Western Electric No. 1 metal for general use on relays because No. 1 metal is not as good from an erosion standpoint and is more costly than palladium.

Polymer failures are not likely to occur on contacts which erode, since the arcing burns away the polymer. However, the gold overlay is applied to all wire-spring relays because it is impractical to know in advance the use to which the contacts of each relay code will be put. About 75 per cent of all contacts in switching systems do not erode, and these contacts will benefit by the gold overlay, which need only be thick enough to provide for the expected mechanical wear. The other 25 per cent of the contacts will erode and, for these, the gold serves no useful purpose. These latter contacts will erode the 1-mil overlay of gold fairly quickly and then obtain their needed erosion life from the underlying 9-mil-thick palladium metal.

II. GENERAL THEORY

When palladium or platinum-family metal contacts are operated in an environment containing organic vapors, a polymer-like substance is formed on the contact surfaces. The polymer forms only on operating,

* An alloy of 69 per cent gold, 25 per cent silver, 6 per cent platinum by weight.

sliding or vibrating contacts. The polymer generation does not depend on the contact current, since it is also produced on unwired contacts. A detailed physicochemical description of the polymer generation and properties is contained in a companion article.[6]

The polymer accumulates in compacted clumps around the actual contact area or in dust on the sides of the contacts. Enough will be generated in 1000 operations of a relay contact to be visible under a microscope. In 100,000 operations, the material is easily visible with a 10-power glass. After several hundred thousand operations, the compactions are large enough to cause contact failure in 50-volt circuits by dusting off and falling into the contacting area. After possibly a half million operations, the polymer dusts away from the contacts at the same rate as it is produced, so that the contact failures then result at a maximum rate. Failures from polymer may also occur because of a shift in the actual contact area caused by a slight change in the contact spring position or a wearing down of a minute metallic roughness in the contact surface. The many factors that affect the failure rate are outlined in Section IV.

The effect of the polymer on actual operating relay contacts has been studied intensively only in 50-volt circuits, since this voltage is most commonly used in telephone switching practice. In such circuits, a contact, having failed, will clear itself, on the average, in about five relay operations. Thereafter, its probability of failure is not much greater than that of other contacts in the same test. This low "persistency" of failure is characteristic of the polymer, whereas fibrous dust failures tend to be much more persistent. Although lower circuit voltages have not been fully explored, it is expected that the failure rates and the persistency of failure will increase as the voltage is decreased.

The polymer is a good insulator and has the characteristics described by Holm[8] for thick highly insulating films. When voltages below the dielectric breakdown value are applied, the resistance of the film is many megohms and the currents are zero or a few microamperes. If the voltage is raised sufficiently, dielectric breakdown occurs, followed by the formation of a metallic filament pulled out of the contact surfaces (coherer effect), and the contact voltage then drops to a value corresponding to the melting-point voltage of palladium, about 0.5 volt. The voltage required to produce such breakdown through the polymer particles has been found to be as high as 270 volts.

Often the polymer is mixed with carbonization or erosion products which lower the film resistance. The polymer film may be carbonized by electrical arcing even on "non-eroding" contacts since the circuit voltage,

when applied to the insulating film, may arc through the film, thereby decomposing it by heat. Also, erosion products form when the relays are operated under conditions of low vapor concentrations and high pulsing rates. The resulting effect is the same as for lightly arcing contacts, in that film resistances of a few ohms are commonly found and high resistances are less frequently obtained.

When the organic deposit is highly carbonized, the contact resistance is usually low and the current is proportional to the voltage. However, if the current is raised sufficiently, thermal breakdown will occur, with an abrupt drop in resistance to a new lower value. The process can be repeated until the melting-point voltage is reached.

III. FAILURE RATES AND UNITS

A 10,000-line No. 5 crossbar central office handles about 50,000 calls per day. Each call requires the operation of about 1000 relays, each relay having an average of seven contacts. Consequently, such a central office has about 100×10^9 relay contact operations in one year.

Maintenance data indicate that such an office, using U-type relays, has about 100 "found" open contacts per year, or, using the above contact operations, about one found open contact per 10^9 contact operations. It is estimated that there are at least 12 times as many failures as this, but these other failures are not persistent enough to be found by the maintenance forces and appear only as transient failures.

The laboratory tests to be described are more efficient at locating troubles than are central office trouble detecting routines. It is estimated that half of the indicated troubles in these laboratory tests are found. Consequently, in these laboratory tests a found trouble rate of about six opens per 10^9 operations would be equivalent to central office experience, but failure rates much higher than this would be a cause for concern.

In the tests to be described, the failure rates are listed on the basis of "opens per 10^9 contact operations". Since each test usually involves several hundred contacts operating several million times each, it would be more descriptive to use "opens per thousand contacts per million operations" as a unit. However, the simpler unit is used for brevity.

In all cases, only the initial failure of a given contact in a series of consecutive contact failures is counted in the failure rate. The successive failures that occur after an initial failure and until the contact clears itself are counted as the "persistency" of failure. The total failures are therefore the failure rate times the average persistency.

IV. FACTORS AFFECTING CONTACT PERFORMANCE

The factors that affect or determine the contact performance of any pair of relay contacts can be classified into four categories: (1) the contacts, (2) the environment, (3) the dynamics of the contacts and (4) the circuit connected to the contacts.

Insofar as the contacts themselves are concerned, it is necessary to consider their size, shape, alignment, smoothness, hardness and composition, as well as the presence of any erosion products, films or particulate matter on the contact surfaces. The contact environment includes the atmosphere, which may be dusty, and any additional vapor or gas, including humidity, that would form films or deposit other foreign material on the contact surfaces. The contact dynamics include the velocity, impact, slide, chatter, force and rate of operation of the contacts. The circuit conditions involve the voltage, current, load inductance and load capacitance and wire capacitance, and whether the contacts close and open with current flowing.

The effect of many of these variables on contact performance in the presence of organic vapors will be described in later sections.

V. METHODS OF TESTING

Many of the variables listed above were explored by direct contact-reliability tests on actual relays. Three types of test setups were used. For convenience, these are called the Open Contact Test Machine (OCTM), the Open Contact Test Unit (OCTU) and the Open Contact Test Frame (OCTF). The OCTM is used for exploratory tests of several months' duration. Single contacts are used to increase the failure rate and only one parameter is varied in each test of 90 contacts. About 40 such tests have been made. The OCTF was used for a direct comparison test of several years' duration. A total of 2000 single and twin contacts on four different relay types were tested simultaneously under a fixed set of circuit and environmental conditions. The OCTU simulates actual field conditions and is operated for a one-year period, using 540 twin contacts under the equipment conditions used in the telephone plant. Ten such tests have been made. Simplified schematics of the OCTM and OCTU are shown in the Appendix (Figs. 18 and 19).

In these tests, the contacts are generally operated and released without contact current so that no contact erosion occurs. However, in some tests the test contacts are allowed to charge the wire capacitance of the succeeding contacts in the series contact chains. This type of contact closure is referred to as "cable charge." The tests in which cable charging

Fig. 2(a) — Open Contact Test Machine (OCTM) is used for exploratory tests of short duration. Single contacts are used instead of twins to increase the failure rate, with usually only one parameter being varied for each test.

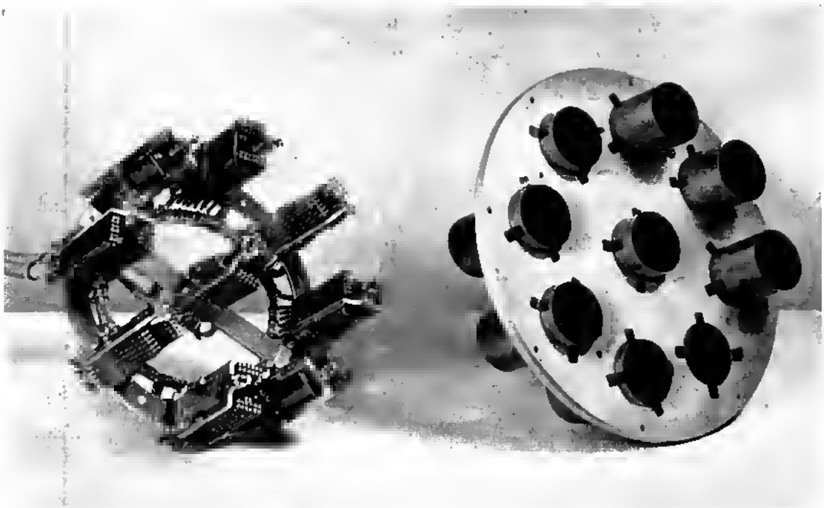


Fig. 2(b) — Close-up of nine test relays and associated streamlining cylinders which are mounted in the upper turret of the OCTM. The streamlining cylinders were removed and a blank plate substituted for these sealed-chamber tests.

by the test contacts is not permitted are referred to as "no cable charge." The test sequence is generally as follows: (1) the test relays are operated, (2) a 50-volt checking circuit is applied through the contacts arranged in series chains, (3) the checking circuit is removed, (4) the relays are released, (5) the cycle is repeated. The cycle is controlled by a mechanical interrupter. If a contact fails, the circuit stops in the failed position until this failure is located, and the circuit is released by the attendant. Unless otherwise indicated, each test is started with new relays and the contacts are replica-cleaned to insure freedom from initial contamination.

The Open Contact Test Machine (OCTM), Fig. 2, consists of 90 normally-open test contacts arranged in series chains of ten contacts per chain. These test contacts are on nine relays that are housed in the upper turret of the test machine. The circuit operation is arranged to stop and hold in the failed position when a contact or series chain of ten contacts produces a resistance greater than 1000 ohms. The checking circuit placed across the series chain of test contacts provides approximately 0.020 amperes at 50 volts. The time the checking circuit remains across the contacts can be varied from 30 to 125 milliseconds.

The OCTM was originally designed with the objective of using it as a dust meter to measure the effect of dust in causing opens on relay con-

tacts. Dusty air can be drawn downward through the streamlining cylinders past the relay contacts while the relays are being operated. For testing organic deposit contamination, the streamlining cylinders are removed and the upper surface is sealed with a tight-fitting plate to obtain a sealed chamber.

The 90 contacts on the nine test relays are wired individually to 90 jacks located on the lower front of the test machine. If a contact fails to close, the machine stops and the failure is indicated by an alarm. An attendant then applies a shunt counting circuit across the failing contact to allow the operation to proceed. The counting circuit counts the number of consecutive contact failures, as a measure of the failure persistency. When the contact open is cleared by these operations, the shunt circuit is disconnected automatically.

The usual rate of operation with the OCTM is at one operation per second. Prior to the start of a new test, the relays are carefully cleaned of dust and fibers by vacuum cleaning and the contacts are cleaned by the replica method. Furthermore, the chamber is never opened once the test is started and the contact troubles are cleared only by the successive operations of the contacts themselves.

The Open Contact Test Unit (OCTU), Fig. 3, consists of 90 test relays, each having three make and three break contacts arranged in series chains of 30 contacts per chain. The relays are enclosed in the covers which are standard for the system in which the relays are used. Thus, in testing wire-spring relays, no frame covers are used, but each relay has its own molded-plastic contact cover. The circuit operation is arranged to stop and hold in the failed position when a contact or series chain of 30 contacts produces a resistance greater than 1000 ohms. The checking circuit, placed across the series chain of test contacts for 30 milliseconds, consists of approximately 0.080 ampere at 50 volts.

If a contact fails to close, the test stops and the failure is indicated by an alarm. An attendant then locates the failing contact by use of an ohmmeter. Failing contacts are cleaned by the replica method. Failure persistency data are, therefore, not obtained in the OCTU.

The usual method of testing with the OCTU is testing of twin contacts at 0.1, 1.0, and 10 operations per second. Prior to the start of a new test all contacts are cleaned by vacuuming and then by the replica method.

The Open Contact Test Frame (OCTF), Fig. 4, consists of 200 test relays, each having five make and five break contacts arranged in series chains of ten contacts. The OCTF is made up of two bays, one housing the relays under test, the other housing both the control relays and the jack field used to obtain access to the failing contact. The test bay is

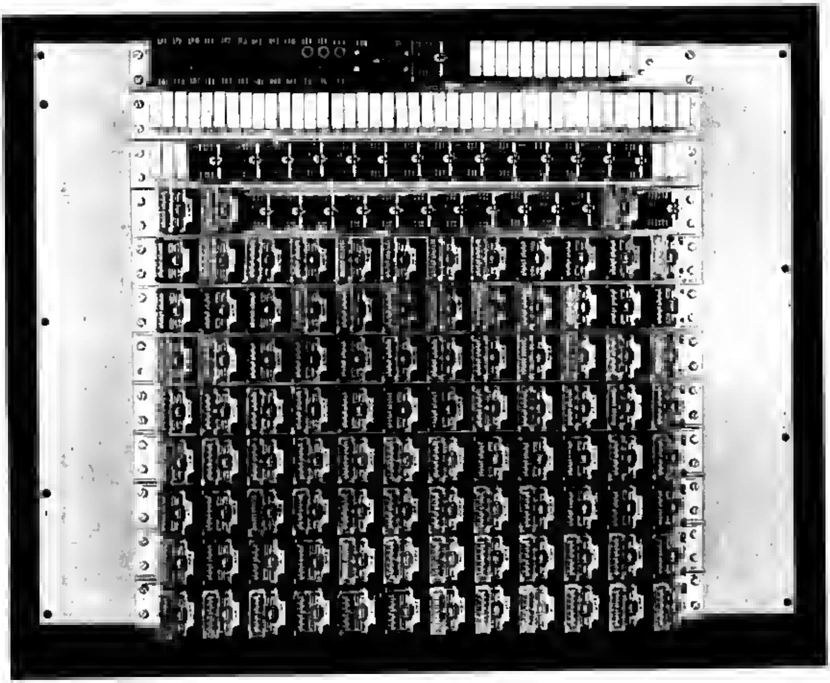


Fig. 3 — Open Contact Test Unit (OCTU) simulates actual field conditions in that twin contacts are operated under equipment conditions used in the telephone plant. Tests are usually operated for more than a year, with contact parameters indicated by exploratory tests in the OCTM's.

sealed and gasketed, with the relays molded into the mounting plates to preserve a dust-tight enclosure. Controlled dusty or filtered air can be admitted by means of blowers and ducts, but this facility was not used in these tests. Four types of general purpose relays, two U-type designs (U and UB) and two wire-spring designs (AF, and M24*), were tested simultaneously, using both single and twin palladium contacts. The circuit operation is similar to that of the OCTU. However, the location and clearing of a failing contact is like that of the OCTM, where failure persistency is obtained. One test was made which included 29 months of operation and the testing of a total of 2000 contacts.

VI. TEST RESULTS

The tests to be described were mainly exploratory in nature, and were designed to indicate trends rather than absolute values. As might be expected in making open-contact failure comparisons, the variability of

* An early wire-spring relay design that was not used in final production.

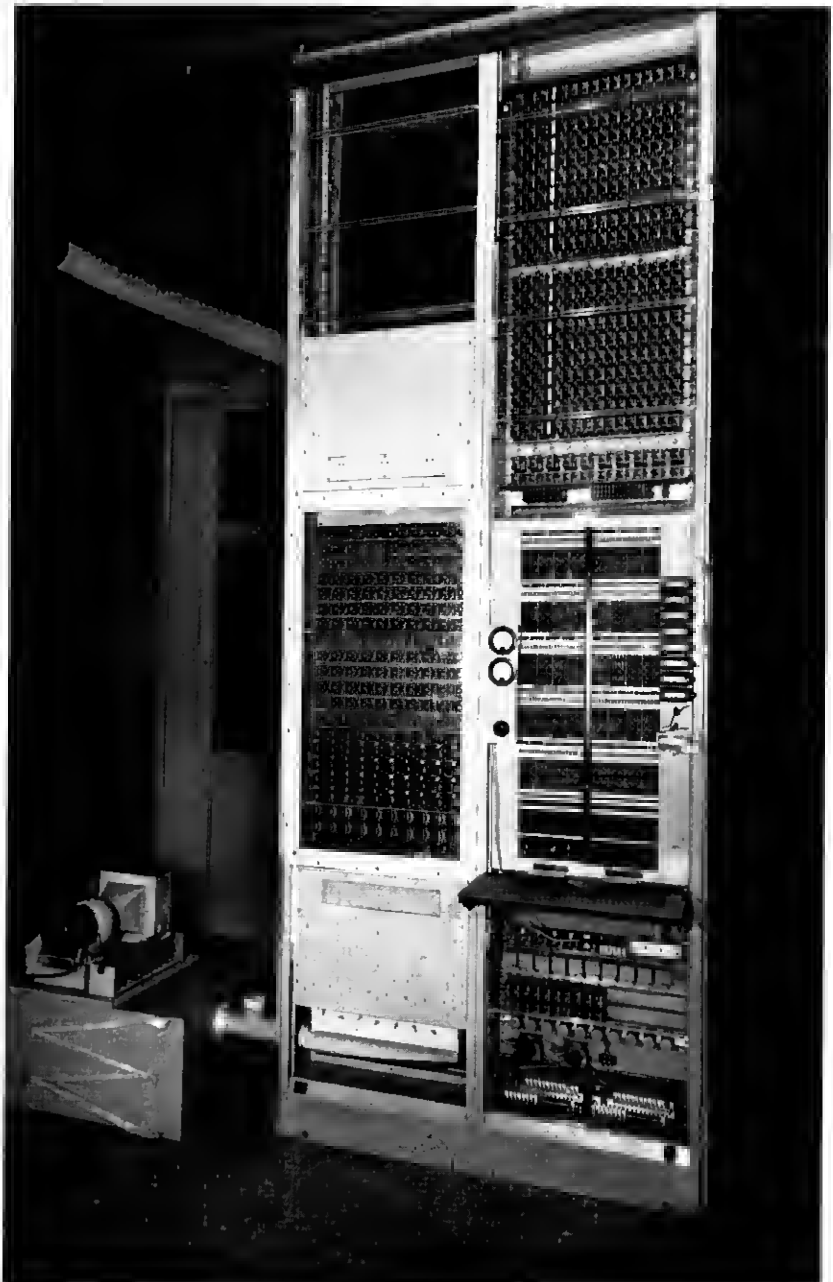


Fig. 4 — Open Contact Test Frame (OCTF) was used for a direct comparison test of several years' duration. Single and twin contacts on four different relay types were tested simultaneously under a fixed set of circuit and environmental conditions.

the data is large, so that differences in performance of less than 2:1 may not be significant.

6.1 *Effect of Kind of Contact Metal*

Palladium contacts are relatively poor performers when subjected to polymer contamination by organic vapors. On the other hand, gold, silver and gold-silver alloys are relatively trouble-free from a polymer standpoint. In one series of tests, these contact metals were tested in the form of heavy-size single contacts on U-type relays in the OCTM units. The alloys used were No. 1 metal (69 Au, 25 Ag, 6 Pt), No. 3 metal (70 Au, 30 Ag), 22-karat gold (92 Au, 8 Ag), and R156 metal (60 Pd, 40 Ag). The results of these tests are shown in Table I.

TABLE I — FAILURE RATES WITH CERTAIN CONTACT METALS SINGLE CONTACTS ON U RELAYS

Contact Metal	Cable Charging on Closure	Relay Operations in Millions	Operations to First Open in Millions	Opens/10^9 Contact Operations	Average Persistency
R156/R156	Yes	1.82	0.07	565	3
Pd/Pd	Yes	2.50	0.31	218	6
No. 1/No. 1	Yes	10.00	0.79	15	2
Pd/Ag	No	1.83	1.03	6	2
No. 3/No. 3	Yes	10.55	—	0	—
22K Au/22K Au	Yes	10.00	—	0	—

A similar series of tests was run on AF-type (wire-spring) relays. In this series of tests, the gold-silver alloys were mostly overlays on palladium. Also tested were certain combinations of these gold-silver alloys mating with palladium contacts. The results of these tests are shown in Table II.

The large improvement obtained with palladium mating with 22-

TABLE II — FAILURE RATES WITH CERTAIN CONTACT METALS SINGLE CONTACTS ON AF RELAYS

Contact Metal	Cable Charging on Closure	Relay Operations in Millions	Operations to First Open in Millions	Opens/10^9 Contact Operations	Average Persistency
Pd/Pd	Yes	1.55	0.10	4250	4
Pd/No. 1	Yes	0.78	0.51	358	16
Pd/22K Au	No	6.23	1.45	271	15
Pd/No. 3	Yes	0.78	0.39	32	10
No. 1/No. 1	Yes	5.08	2.32	4	2
No. 3/No. 3	Yes	10.00	9.30	1	5
22K Au/22K Au	No	3.00	—	0	—
Ag/Ag	Yes	7.28	—	0	—

karat gold indicated that this combination might perform very well as twin contacts. This is the combination that was finally used on wire-spring relays. The final test using twin contacts is described in a later section.

6.2 *Effect of Contact Shape*

A series of tests was made of various shapes of palladium contacts on U-type relays to investigate the possibility of obtaining improved performance over the performance of the present heavy palladium (large-area) contacts. It was found that no worthwhile reduction in polymer failures could be obtained by changing the contact shape.

These tests were conducted in the OCTM units. The contact shapes tried, some in combinations, are shown in Fig. 5. In all cases, the mating contacts were assembled on the springs so as to form crossed-bar contacts.

The results of these tests, all with palladium contacts, are summarized in Table III.

It is evident that the contact shape that tends to produce the maximum contacting area produces the smallest failure rate from polymer.

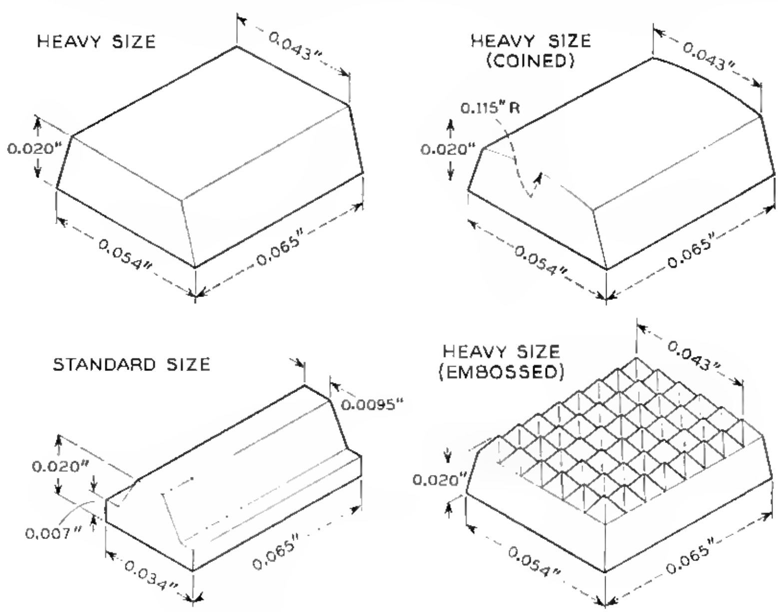


Fig. 5 — Various shapes of palladium contacts used on U-type relay tests in the OCTM's.

TABLE III — FAILURE RATES WITH CERTAIN CONTACT SHAPES
SINGLE PALLADIUM CONTACTS ON U RELAYS

Contact Form	Cable Charging on Closure	Relay Operations in Millions	Operations to First Open in Millions	Opens/10^9 Contact Operations	Average Persistency
Coined/Coined	Yes	0.60	0.20	1196	5
Coined/Hvy	Yes	0.34	0.17	391	5
Emb/Hvy	Yes	1.06	0.13	385	4
Std/Std	Yes	1.27	0.27	306	3
Hvy/Hvy	Yes	2.50	0.31	218	6

Similar results were found in earlier contact tests[9] made at the Laboratories, in which the contact contaminants were limited to dust particles less than 25 microns in diameter. On the other hand, in these earlier tests, when the contaminating dust was changed to larger-particle lint and paper fibers, the opposite trend for the effect of contact shape was observed.

An explanation for the observed effect of the contact shape on the failure rate from polymer is deferred to the next section. It should be noted that, in addition to changing the contact shape, the coining and embossing operations work-harden the contact surfaces and improve the microscopic smoothness. These factors also affect the failure rate.

6.3 *Effect of Contact Alignment*

Typical distributions of open-contact failures on palladium contacts of U and AF relays in OCTM tests are shown in Fig. 6. This graph shows that some contacts are relatively prone to failure while others, supposedly identical, never fail. Attempts have been made to explain why contacts differ so greatly in their performance. It is speculated that the difference between such contacts is partly one of alignment of the contacting surfaces, and that polymer-caused open-contact failures on palladium contacts would be minimized if the contacts could be made flat and be aligned so as to tend to produce a maximum contacting area.

A study of contact replicas taken from U-relay contacts at the completion of a test supports this speculation. Contacts which have a history of contact failures produce replicas like those of Fig. 7(a), while contacts that have not failed produce replicas like Fig. 7(b). It appears that, with good alignment, the polymer films remain thin and the true conducting spots may be spread over quite an area. These conducting spots are very small, being on the order of 10 to 20 microns in diameter. If one such conducting spot wears down or becomes insulated by a fine polymer dust, electrical contact may be made via the other conduct-

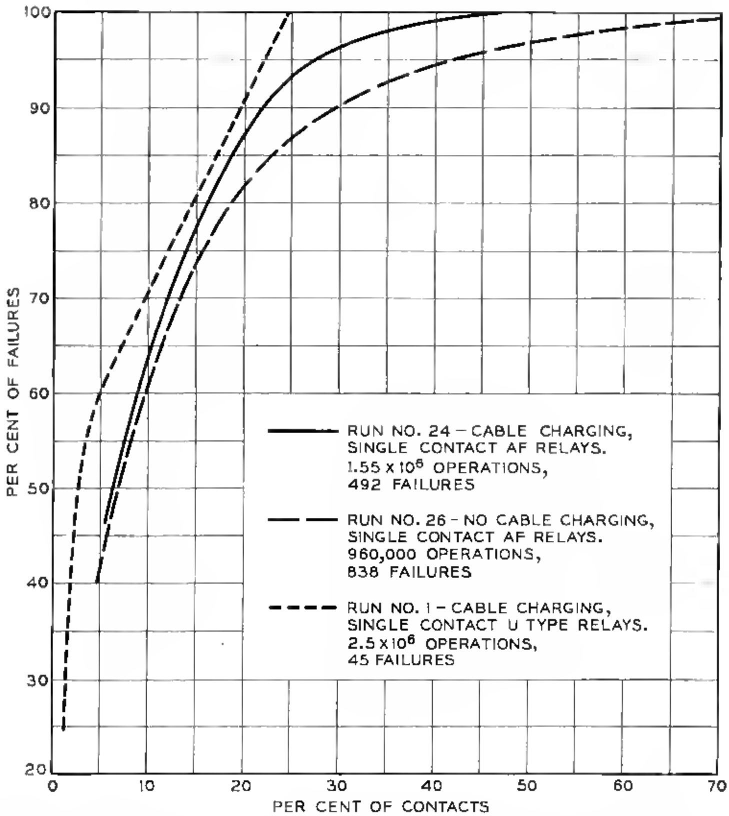
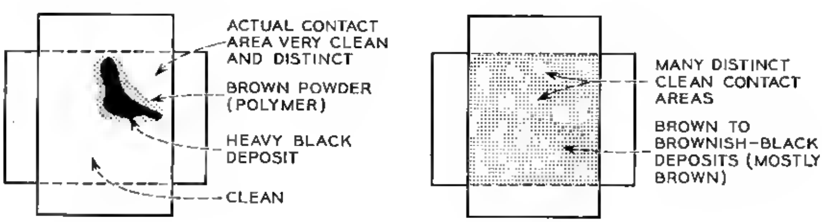


Fig. 6 — Distribution of open-contact failures on palladium contacts of U and AF relays in OCTM tests.



(a) (b)

Fig. 7 — Sketches of replicas of single contacts of U-type relays: (a) poor alignment — produces opens (b) good alignment — does not produce opens.

ing spots, and the contact will not fail. With poor alignment, the contacts form compacted aggregates of polymer surrounding a very limited contact area. If the true conducting spots wear down, another electrical contact cannot be made in the compacted ring of polymer, and the contact fails. Also, the compacted polymer may break off and cause contact failure by falling into the contact area. Contacts which have been coined or embossed to present only a small contacting area behave like misaligned flat contacts, and therefore have a relatively high failure rate, as indicated in the results of the previous section.

6.4 *Effect of Operating Rate*

The operating rate is a major factor in the open-contact failure rate. When the operating rate is low, not enough polymer forms and the

TABLE IV — FAILURE RATES WITH THREE OPERATING RATES
TWIN PALLADIUM CONTACTS ON AF RELAYS

Number of Test Contacts	Operations per Second	Relay Operations in Millions	Total Opens	Operations to First Open in Millions	Opens per 1000 Contacts/Year	Opens per 10^9 Contact Operations
120	0.1	0.39	4	0.15	33	86
120	1.0	3.88	48	0.59	400	103
120	10.0	38.80	13	1.59	108	3

failure rate, per unit of time, is low. If the operating rate is high, the composition of the organic deposit apparently changes and the failure rates are also found to be low. However, at intermediate operating rates such as one operation per second, sufficient polymer with highly insulating properties is formed to produce a high failure rate per unit of time. The data shown in Table IV were derived from an OCTU, using AF-type relays having twin palladium contacts and individual molded-plastic contact covers but no frame covers. The test was operated for one year.

Since this test showed that failure rates per unit of time are greatest with a relay operating rate of about one operation per second, and since the common control circuits of crossbar systems use relays at about this operating rate, most of the other tests were conducted using a rate of one operation per second. Several attempts were made to accelerate the tests by using higher operating rates and by applying a correspondingly increased vapor concentration with the use of limonene, as had been done in the study of the effects of organic vapor on contact erosion.

The increased vapor concentration, however, apparently affected the physical makeup of the polymer, so that it was kept more fluid and did not produce the failure rates obtained at the lower operating rates. These accelerated tests were therefore discontinued.

6.5 *Effect of Operational History*

The failure rate is significantly affected by the previous operational history of the contacts. The failure rates are low until several hundred thousand operations have produced enough polymer to cause open-contact failures. Thereafter, the maximum failure rates are encountered, sometimes decreasing gradually with operations. As will be shown in other tests to be described, the decrease in failure rate may result from somewhat better alignment or fit of the contact surfaces, resulting from mechanical and electrical erosion of the contact surfaces. It is not due primarily to a general drying out of the volatile components of the relay structures, although this may be a secondary cause of the observed effect. The following data were derived from an CCTU with AF-type relays using twin palladium contacts and individual molded-plastic contact covers but no frame covers. This OCTU had had a year's operation (the test described in Section 6.4), with the relays being divided into three groups, each having a different rate of operation, as shown. Before the start of the new test, all contacts were replica-cleaned. The test was then restarted with all relays operating at the uniform rate of one operation per second, with results shown in Table V.

The performance of the contacts that had the history of 38,800,000 previous operations is remarkably good. The improvement does not seem to be due to a reduction in the ability of the contacts to produce polymer, because, at the end of the test, a replica examination failed to show any difference in the amount or kind of organic deposit formed on the contacts of the three groups. In the succeeding sections several tests are described which explore this effect further.

TABLE V — FAILURE RATES WITH DIFFERENT OPERATIONAL HISTORIES TWIN PALLADIUM CONTACTS ON AF RELAYS

Previous History		New Test (After Cleaning)			
Operations per Second	Relay Operations in Millions	Operations per Second	Relay Operations in Millions	Number of Opens	Opens Per 10^9 Contact Operations
10.0	38.8	1.0	2.0	0	0
1.0	3.88	1.0	2.0	10	27.7
0.1	0.39	1.0	2.0	32	88.8

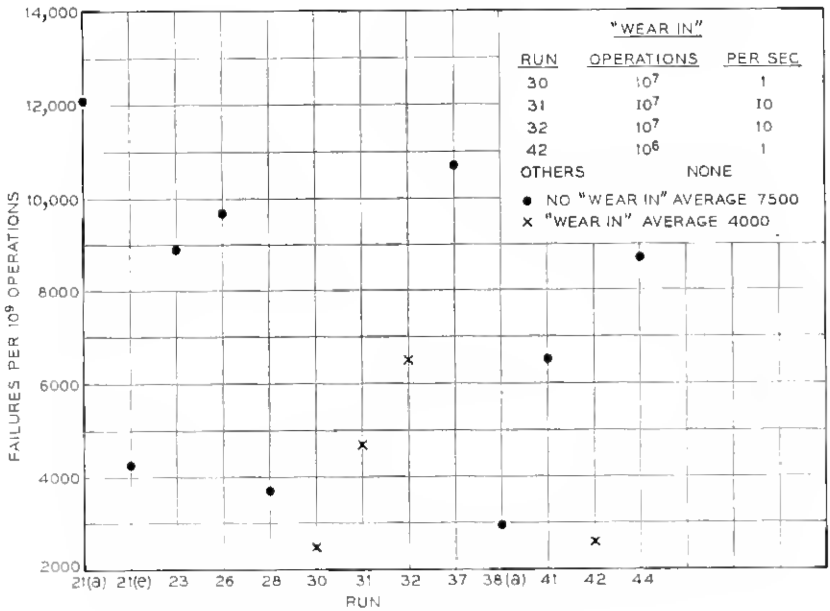


Fig. 8 — Effect of mechanical wearing-in of contacts.

6.6 *Effect of Non-Electrical Operation of Contacts*

The reduction in failure rates that is found on relays with a previous operational history suggests that the contacts "wear in" mechanically, thereby improving the contact fit and changing the surface roughness. To check this hypothesis, four groups of nine test relays each were operated at rates of one or ten operations per second without wires on the contacts. One of these groups was operated for one million operations and three for ten million operations. Each of these groups of relays were then wired into an OCTM, the contacts being replica-cleaned in each case. It was found that the failure rate in these four tests averaged about one-half the failure rate obtained for nine other tests using relays which were not subjected to an earlier wear-in. The data are shown in Fig. 8. This difference, however, may not be statistically significant because of the large variability in the data. The improvement in contact performance that is obtained with contacts that have had a previous operational history also seems to be associated with electrical operation of the contacts. This effect is explored in the succeeding sections.

6.7 *Effect of Charging of Wire Capacitance on Contact Closure*

Under some circuit conditions, contacts close without potential difference and open without current. Such contacts are electrically non-

eroding. Under other circuit conditions, the operation may differ only to the extent that the contacts, upon closure, charge the capacitance of a few feet of wire. Such contacts are also classed as non-eroding contacts, although it is obvious that minute erosion must take place, inasmuch as a potential difference exists when the contacts close. For brevity, contacts of the first type are called "no cable charge" (NCC) contacts and contacts of the second type are called "cable charge" (CC) contacts. From a failure standpoint, the NCC contacts are appreciably worse than the CC contacts.

To determine the effect of cable charging closure upon the failure rate, an OCTM was operated with the contacts of five AF relays connected without cable charging on closure and the contacts of four other relays connected with cable charging. The failure data are plotted in Fig. 9. For the first million operations, the NCC contacts had 3.3 times the failure rate of the CC contacts. At one million operations, the contacts were all replica-cleaned and the NCC contacts were changed to CC operation, so that all contacts were then connected alike. The failure rate dropped for both groups and became more nearly equal, but the contacts with the early history of NCC operation still showed a 50 per cent higher failure rate. At three million operations, the contacts were again replica-cleaned and reconnected as they had been initially. The failure rates again dropped, this time to insignificant failure rates for each group.

There seem to be two distinct explanations for the effect of the electrical circuit in reducing the failure rates noted in this test. On the one hand, the capacitance-charging current on closure appears to burn and carbonize the polymer, thereby reducing the open-contact failure rate.

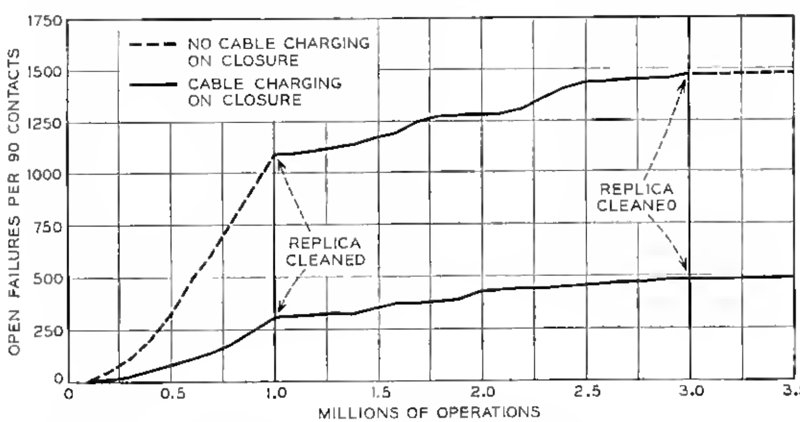


Fig. 9 — Effect of charging of wiring capacitance on contact closure.

However, the capacitance-charging current appears also to have a permanent effect on the contact surfaces, since the failure rates drop abruptly and remain permanently lower after each cleaning. Even in the case of contacts having no cable charging on closure, some arcing takes place when the polymeric films are punctured by the 50-volt checking voltage. This arcing alone is enough to improve the contact performance, being almost as effective as the cable-charging currents on closure.

It is apparent that this type of arcing produces a permanent improvement in the contact performance. The arcing burns off the larger irregularities on the contact surfaces, thereby tending to increase the fit or alignment of the contacts. It also increases the microscopic roughness, increasing the number of potential conducting areas and possibly reducing the failure rate from fine particles, by the mechanism described by J. B. P. Williamson, J. A. Greenwood and J. Harris.[10]

A further attempt to explore the effect of arcing on the contact performance is described in the next section.

6.8 *Effect of Contact Erosion*

Precious metal contacts, when used in a circuit arrangement that results in contact erosion, have a very low failure rate from dirt or organic films. For example, during earlier laboratory contact erosion studies in which thousands of contacts were operated millions of times, the failure rate from dirt and films was only 0.01 failure per 10^9 contact operations — a remarkably low failure rate. The obvious explanation is that heavy arcing burns away dirt and films thereby keeping the contacts clean.

The preceding section, however, indicates that the arcing may also produce a permanent improvement in the contact surfaces. To test this possibility, a group of nine AF relays with a total of 90 single contacts was operated in a sealed container, each contact opening and closing a non-inductive load of 2500 ohms, with a 50-volt battery. The relays were operated 80,000 times each, at which time it was evident by oscilloscope observations of the increased arcing that the contacts had become severely activated from organic vapors.[3] The erosion due to this treatment was insignificantly small because of the low number of operations. However, because of the presence of organic vapors, the arcing eroded the contacts over a large area with microscopic roughness, but without large buildups and pits. At the end of this priming procedure, half of the contacts were replica-cleaned and the 90 contacts were then operated in the OCTM without cable charging in the usual fashion. The failure rates for these slightly eroded contacts were found to be one-

tenth to one-fifth of the values normally found for new AF relay contacts, the cleaned contacts being twice as good as the uncleaned contacts.

This experiment was repeated using contacts that were roughened in the open air by the erosion that occurs from 1000 operations of an inductive relay load. This type of erosion produced larger pits and build-ups on the contact surfaces and did not improve the fit. The failure rates were found to be as high as for new untreated contacts.

These many experiments show consistently that polymer failures, and probably failures from very fine dusts, will be minimized if the contacts are large in area, well aligned so as to provide a good contact fit and having surface roughnesses limited to microscopic size.

6.9 *Effect of Relay Coil Temperature*

When AF- or U-type relays with palladium contacts are operated without enclosures on duty cycles so low as to produce essentially no temperature rise in the coils, the failure rates are acceptably low. However, if appreciable coil heating takes place, the vapors given off by the organic insulating materials in the relay increase the contact failure rate enormously.

Fig. 10 shows the effect of relay coil temperature on the failure rate of AF-type relays with twin contacts. These data were obtained in six separate tests, in which more than 1100 contacts are represented. Most of the tests ran a year or more; one test ran for 29 months. The graph indicates that the failure rate at 68°F is one open per 10^9 contact operations, and that the failure rate doubles for every 10°F increase in coil temperature. A relay coil at 135°F indicates a rate of 100 failures per 10^9 contact operations. Such coil temperatures are easily achieved in telephone switching common control circuits: a 700-ohm relay with a 25 per cent duty cycle or a 270-ohm relay with a 20 per cent duty cycle, each in an ambient of 100°F, would produce such coil temperatures and corresponding trouble rates.

In these tests, the air in the vicinity of the contacts became warmer and drier at the higher coil temperatures, and this is possibly an additional factor affecting the failure rates. The relative importance of these factors has not been resolved.

6.10 *Effect of Relay Insulating Materials*

In the earlier investigation of the effect of organic vapors on contact erosion,[3] it was found that all the relay insulating materials, including

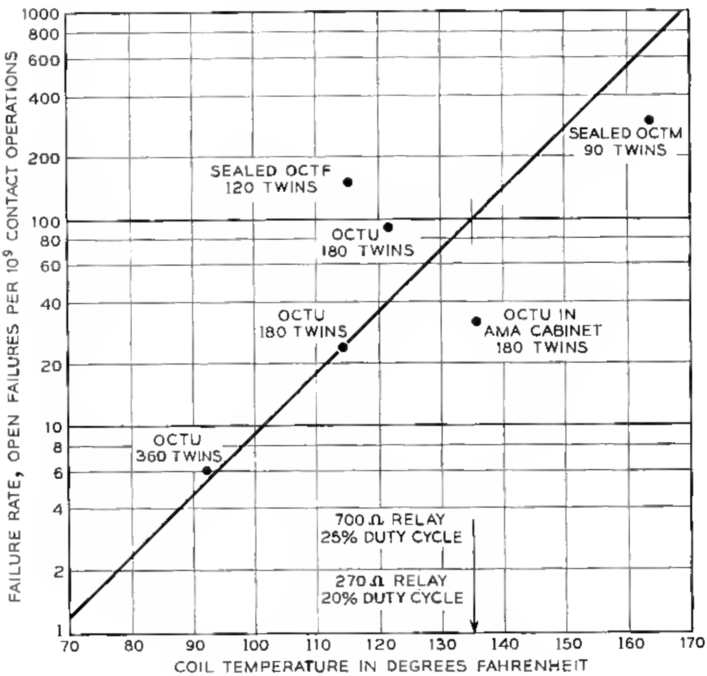


Fig. 10 — Effect of relay coil temperature.

the oleo-resinous wire insulation, the cellulose acetate sheets used in the coil construction and the phenol fiber spoolheads and insulators, were important sources of vapor. It was necessary to replace all these materials by inert materials (glass insulated wire, glass spoolheads, glass insulators, etc.) to prevent vapor contamination of the contacts.

The insulating materials used in modern relays are desirable for economy, freedom from corrosion and good dimensional stability with varying temperature and humidity. Other insulating materials may be found which have all these virtues and which also provide freedom from organic contamination of relay contacts, but such materials are not yet available.

On the AF-type relay, the plastic contact covers and the phenol fiber armature cards enclose the relay contacts. This design differs from the U relay design, which does not use contact covers. To determine the effect of the proximity of these parts on the contact failure rate, an OCTU with AF-type relays was operated using metal armature cards and metal contact covers. No significant reduction in failure rate

was obtained, indicating that the card and contact cover are not the major causes of the difficulty, and that no improvement can be expected by the use of other materials for the card and contact cover that enclose the contacts.

6.11 *Effect of Humidity*

Humidity has a pronounced effect on the failure rate and the persistency of failure. In one test, nine 2500-ohm AF-type relays were tested in the sealed OCTM chamber. The test was run at normal uncontrolled humidity (40–60 per cent) for 1,420,000 operations. Thereafter the test was alternated abruptly between 15 and 85 per cent humidity, using a test period of one week or more for each humidity.

The procedure followed for the cycling of the high and low humidity was as follows:

(1) The test was stopped at noon on Friday and the conditioning material (water or silica gel) was removed.

(2) The chamber was dried, when necessary, and aired out. The relay contacts were protected against dust during this step.

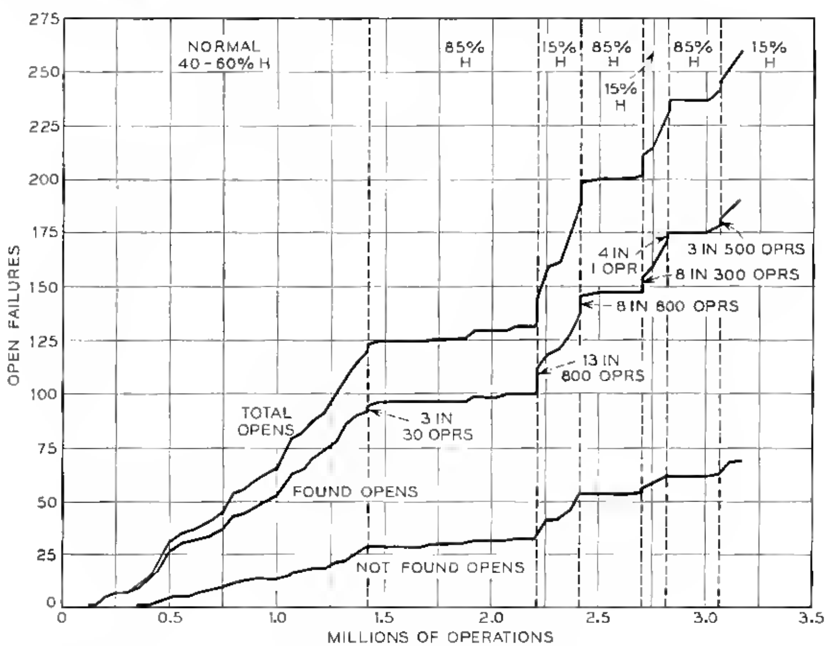


Fig. 11 — A plot of open failures against operations, showing the effect of humidity.

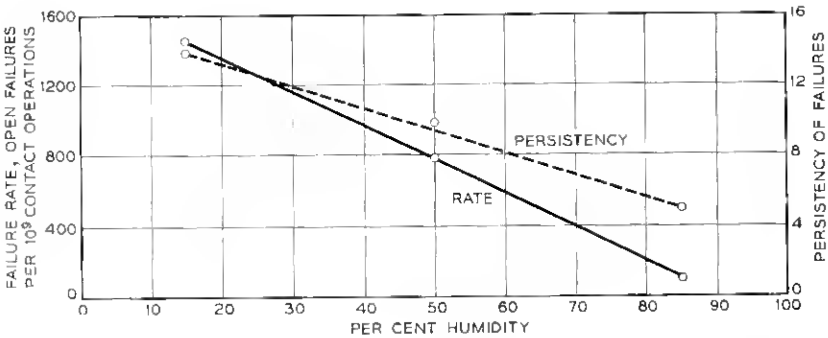


Fig. 12 — A plot of open failures and the persistency of those failures against humidity.

(3) The new conditioning material (water or silica gel) was placed in the chamber. The chamber was sealed and the atmosphere allowed to stabilize over the week-end.

(4) The week's test was restarted on Monday morning.

A plot of open failures against number of operations for the entire test is shown in Fig. 11. Three curves are shown: (1) found opens, (2) not found opens and (3) total opens. Also shown are the humidity values for each part of the test.

When the test was restarted for each new condition of humidity, a flurry of failures occurred within the first 1000 operations or less. These failures are also shown in Fig. 11. The failures occurring at these transition periods are possibly due to a shift in the actual point of contact resulting from a slight physical change in the relay's insulating parts caused by the change in humidity. The failures may also be partly due to a change in the volume of the polymer which had caused it to enter the contact area.

Discounting the flurries of opens that occurred during the transition periods, the failure rates for "wet", "normal" and "dry" humidity conditions are 100, 780 and 1340 opens per billion contact operations. Corresponding persistencies of these failures are 4.9, 9.8 and 12.8 respectively. A plot of these rates and persistencies is shown in Fig. 12. It is interesting to note that there is a linear relationship between humidity and rate of failure, and between humidity and persistency: the lower the humidity the higher the rate of failure and persistency. The following explanation appears reasonable. The polymer takes on more water as the humidity increases, becoming less dusty and less likely to fall into the contact area. Conversely, the drier the polymer

becomes at low humidity, the better the chance for powdery aggregates to fall into the contact area and thus produce contact failures. Tests have shown that the quantity of polymer generated is not affected by humidity.

6.12 *Effect of Relay Design Variations*

The contact performance of palladium contacts in the presence of organic vapors is intimately connected with the relay design and contact spring actuation. In the OCTF a direct comparison was obtained of the M24-, U-, UB-, and AF-type relays (Fig. 13), each with single and twin contacts (Fig. 14). This test was operated for 29 months. The contacts, in all cases, closed without cable charging. The failure rates listed in the Table VI remained essentially the same after the first few months. The actual data are plotted in Figs. 15 and 16.

The M24, U, and UB relays each have 26 grams contact force per twin contact, whereas the AF relay has 13 grams. The M24, U, UB, and AF relays have, in the order named, decreasing contact slide during contact closure. It is believed that the remarkable difference in contact failure rates for these relays is due to these two factors. The peculiar

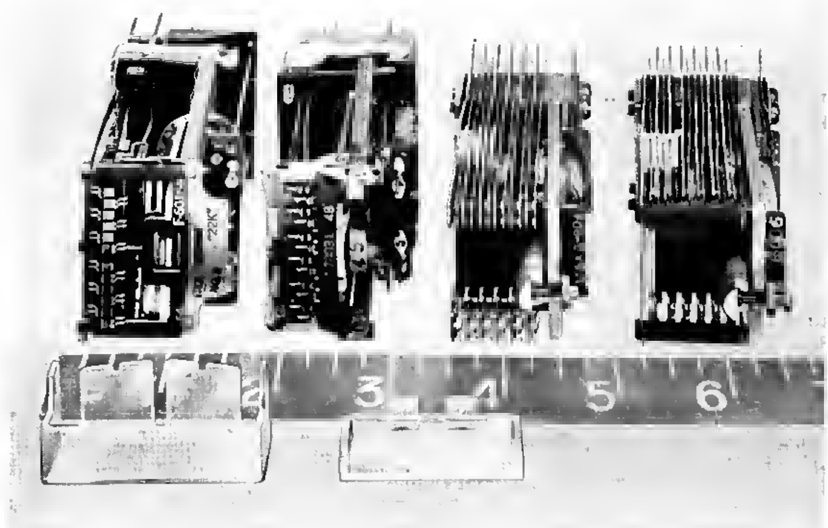


Fig. 13 — From left to right: wire-spring relays AF and M24, U- and UB-type relays. In foreground are individual plastic contact covers for the AF and M24 relays, respectively.

TABLE VI — FAILURE RATES WITH DIFFERENT RELAY TYPES

Relay	Single Palladium Contacts		Twin Palladium Contacts	
	Opens per 10^9 Contact Operations	Persistency	Opens per 10^9 Contact Operations	Persistency
M24	24	4.0	1	20.5
U	400	7.6	5	11.9
UB	2570	10.8	32	18.3
AF	4150	6.3	148	14.8

relations between the single- and twin-contact failure rates and persistencies are discussed in another section.

6.13 *Effect of Contact Velocity*

The magnitude of the contact-closing velocity has a significant effect on the failure rates of palladium contacts. As the velocity is increased, the impact and resulting slide is increased with a corresponding decrease in the open-contact failure rates.

It is found in the OCTU and OCTF tests of the AF relays that normally-open single contacts (makes) fail about three times as often as normally-closed single contacts (breaks). Similarly, normally-open twin contacts fail about ten times as often as normally-closed twin contacts. Since the contact actuation of normally-closed and normally-open contacts is the same on the AF relay, and since these relays are operated on about a 50 per cent duty cycle providing equal closed and open intervals, it

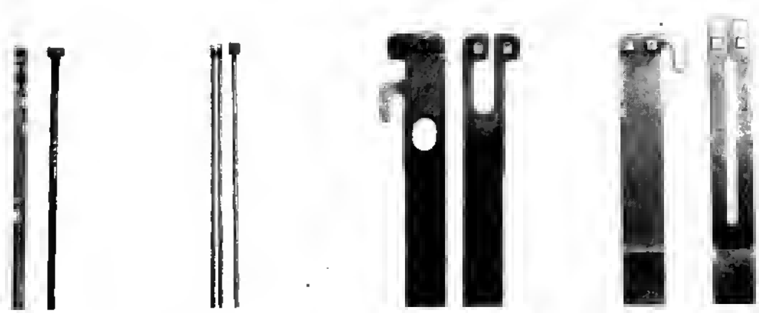


Fig. 14 — Mating twin contact pairs of AF, M24, U and UB relays. The AF and M24 twin contacts are coined to a cylindrical shape, the other contacts have flat surfaces. The AF and M24 twins are made up of two singles which are relatively closer together than in the U and UB relays. Also, the AF and M24 have a common fixed contact, while the U and UB have individual contacts.

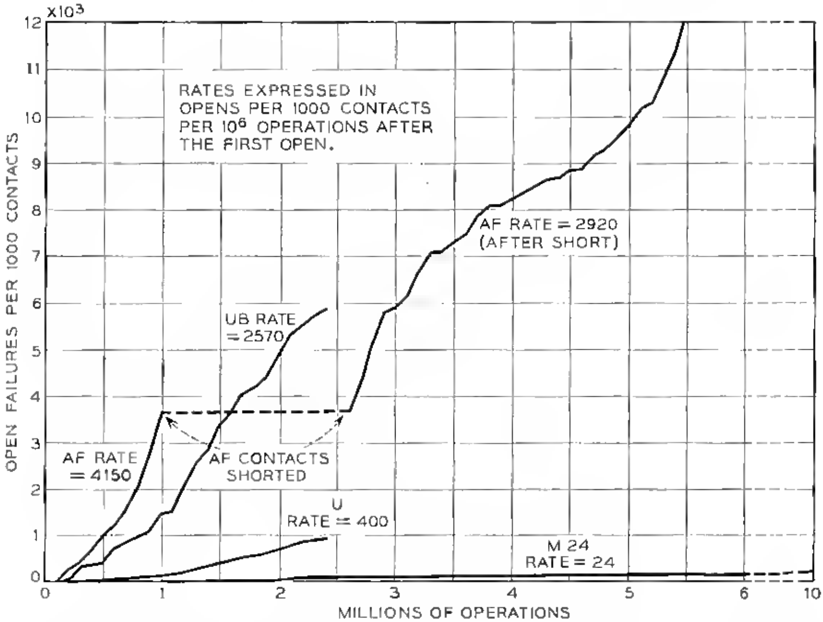


Fig. 15 — A plot of single-contact open failures against operations for AF, M24, U and UB relays operating in the OCTF test.

is concluded that this difference in failure rates must be due to a difference in contact-closing velocity.

A check on this hypothesis has been obtained in the OCTM by comparing contact failure rates on relays which have different contact-closing velocities. Contacts on 16-ohm relays were compared with contacts on 700-ohm relays in order to obtain two different contact-closing velocities. The 16-ohm relays were operated in series with 90-ohm resistances mounted outside the compartment, thereby providing the same power dissipation and temperatures for the two kinds of relays in the compartment. It was found that the higher velocity 16-ohm relays had about one-third the failures of the slower 700-ohm relays.

Other evidence for effect of velocity was obtained in the OCTF, where certain AF-type relays which were deliberately slowed both on operate and release by means of series and shunt resistances were found to have the very high failure rate of 2610 opens per 10^9 contact operations. This failure rate was the highest steady-state failure rate experienced on twin contacts in the entire test program. When the series and shunt resistances were removed to obtain high velocity, the failure rate jumped to the enormous figure of 69,000 opens per 10^9 operations during the next

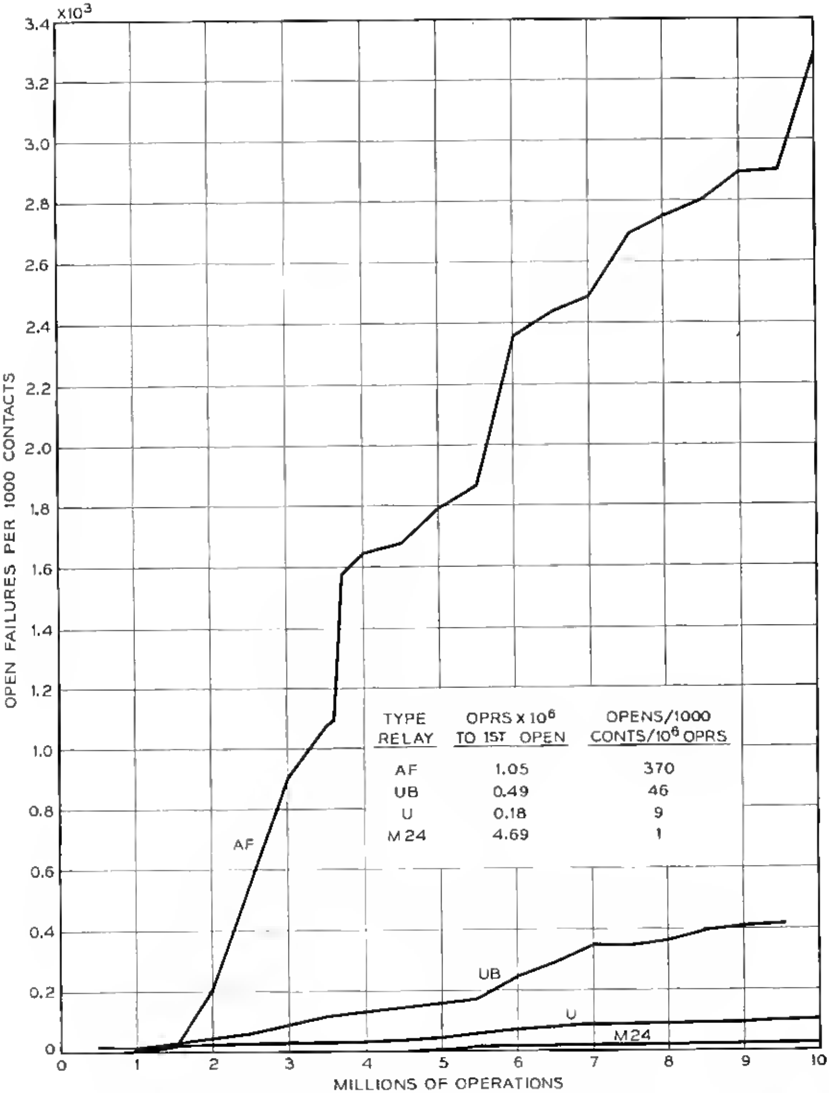


Fig. 16 — A plot of twin-contact open failures against operations for AF, M24, U and UB relays operating in the OCTF test. The failure rates are higher than those shown in Table VI because the low-velocity relay data described in Section 6.13 are included.

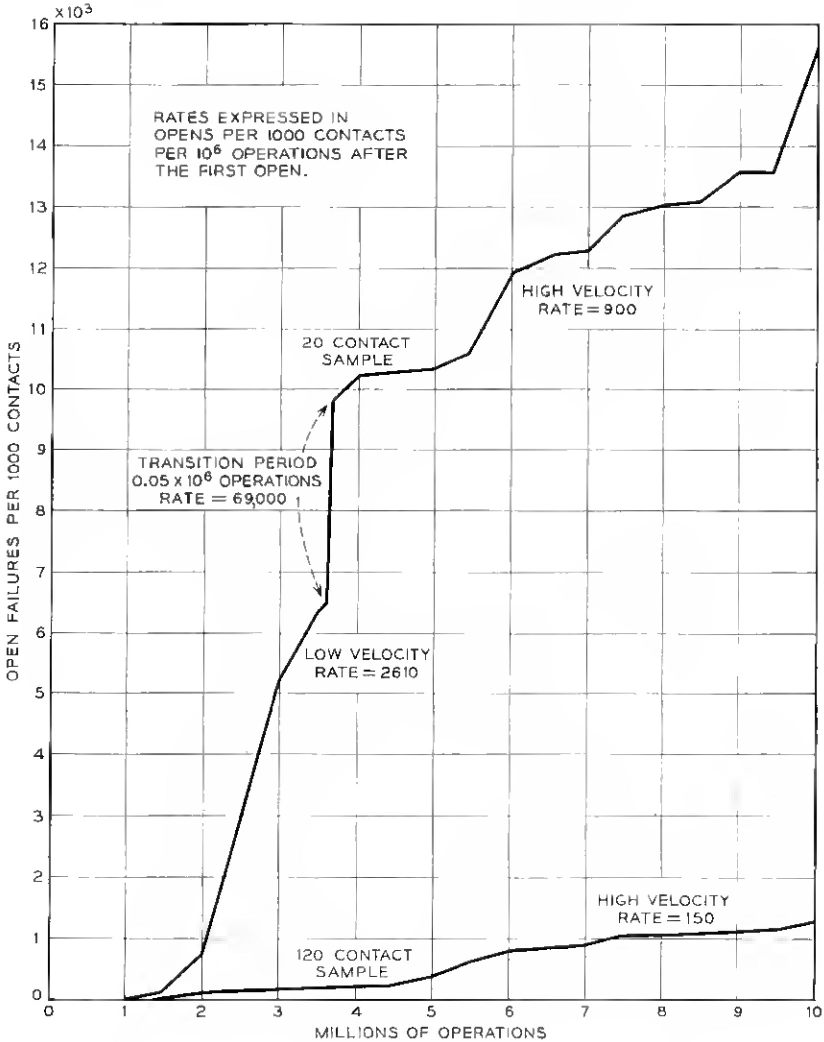


Fig. 17 — A plot of AF wire-spring relay twin-contact failures against operations, showing the effect of contact-closing velocity.

50,000 operations before settling down to the lower rate of 900 opens per 10^9 operations. It appears that the lower velocity and therefore lower shock of the low-velocity test relays allowed a heavy accumulation of polymer in the vicinity of the contact and thereby increased the failure rate. When the velocity was abruptly increased, the polymer was disturbed, fell into the contact area and temporarily increased the failure

rate. Comparison relays with high velocity in the same test had a failure rate of only 150 opens per 10^9 operations. The data are shown in Fig. 17.

6.14 *Effect of Vibration*

External vibration is a serious cause of contact failures on relays having normally closed palladium contacts. The vibration, provided it is severe enough to overcome the static friction of the closed contacts, causes a slight contact slide which, in the presence of organic vapors, produces polymer very near the true contacting area. The contacts may then fail in the same fashion as operating contacts, by producing an open, low resistance or noisy transmission.

The vibration effect can be surprisingly large. In several tests using single palladium normally-closed contacts on wire-spring relays subjected to vibration and vapors from a large number of other wire-spring relays, more than one-third of the contacts were found to register open circuits after several hundred hours of the test. When the contact force was doubled, or when the closed contacts carried a continuous current to burn and carbonize the polymer, the failure rates were found to drop sharply. The contacts had the usual low-persistency characteristic of operating contacts in that a few mechanical operations cleared the open.

As was the experience in the relay operating tests, 22-karat gold, No. 1 metal, No. 3 metal and silver performed much better than palladium in the presence of organic vapors.

6.15 *Relation Between Single and Twin Failure Rates and Persistencies*

If each contact of a twin pair were electrically and mechanically independent of each other, then the failure rate of the twin pair, neglecting its persistency of failure on successive operations, would be related to the failure rate of a single contact by the formula $F_T = (F_s\bar{P}_s)F_s = F_s^2\bar{P}_s$, where F_s is the single failure rate, not including its persistency of failure on succeeding operations and $\bar{P}_s$ is the average persistency of such failures. Similarly, the average persistency of failure of the twin pair would be related to the average persistency of failure of the single contact by the formula $\bar{P}_T = \frac{1}{2}\bar{P}_s$.

These formulae completely fail to predict twin contact performance from the data taken on single contacts. In the OCTF the AF relay, with halves of the twin contacts removed to provide single contacts, had a failure rate of 4150 opens per 10^9 operations and an average failure persistency of 6.3. The above formulae would predict a twin failure rate of 0.1 failure per 10^9 operations and an average persistency of 3.15. The twin contacts in the same test had an actual failure rate of 148 opens per 10^9 operations and an average failure persistency of 14.8, showing that the formulae do not apply.

The failure of the simple formulae to apply can be ascribed to the fact that twin contacts are neither electrically nor mechanically independent. From an electrical standpoint, one half of the twin pair will inevitably be more vulnerable to carbonization of the polymer film by the testing voltage and current. The other twin contact, shunted by its lower-resistance twin, will not suffer electrical degradation of the polymer, since it will never be subjected to a voltage breakdown and will never carry the electrical current unless the other twin has failed. Consequently, the failure probabilities of the two halves differ greatly and the twin failure rate cannot be easily determined from data on single contacts. Also, from a mechanical standpoint, the twin contacts are not independent, since polymer generated on either twin may contaminate the other. The amount of such mutual contamination depends on the proximity of the twins and whether the fixed contact is a single-bar contact, as in the AF- and M24-type relays, or two twin bars as in the U and UB relays.

A number of tests have indicated that this lack of electrical and mechanical independence is the cause of the high twin failure rates. Additional probing tests are being made to investigate this effect more completely.

Empirical formulae which relate the single and twin failure rate actually measured in the OCTF and the OCTM are as follows.

For wire-spring relays AF and M24, $F_T = 1/28\ F_s$, and for U and UB relays, $F_T = 1/80\ F_s$. The AF and M24 twins are made up of two singles relatively closer together than in the U and UB relays. Also, the AF and M24 have common fixed contacts, whereas the U and UB relays have individual fixed contacts. These differences are apparent in Figs. 13 and 14 and appear to explain the higher failure rates of twins relative to singles on the AF and M24 relays.

6.16 *Low-Resistance Characteristics*

In the 50-volt, 20-milliampere, automatic checking circuits used in these tests, the contact resistance is always found to be less than 20 ohms or more than 100,000 ohms. If the insulating film has sufficiently high intrinsic resistance and sufficient dielectric strength, practically no conduction takes place. Under such conditions, very high resistances above 100,000 ohms are measured, and these are referred to as "open" contacts. However, if dielectric breakdown by ionization from the voltage or thermal breakdown from the current occur, the power dissipation in the contact surfaces will be too great at intermediate contact resistances, and breakdown will proceed until the lower range of contact resistance results. Of course, if the circuit voltage is kept low or if the circuit impedance is kept high, the power dissipation at the contacts

will be limited and intermediate values of resistance would then be expected.

The low-resistance effect, unlike the random open contact failures, tends to remain fairly consistent from operation to operation throughout the test. In general, a particular contact that develops the low-resistance effect does not produce open contacts, and vice versa. For example, palladium contact tests on U-type relays in the OCTM consistently showed that approximately one-third of the contacts would develop low resistance, one-third would fail randomly from opens and one-third of the contacts would produce neither low resistance nor open contacts. Gold and gold-silver alloys show only the low-resistance effect, but not on all contacts in a given test; the others have practically no resistance. The distribution of resistance measurements made on various contact metals on U-type relays in OCTM units during open-contact test runs is shown in Table VII. All resistance measurements were made with 1.5 volts and 40 to 80 milliamperes. High resistance measurements that occur with open contacts are not included.

TABLE VII — DISTRIBUTION OF CONTACT RESISTANCE WITH VARIOUS METALS. SINGLE CONTACTS ON U RELAYS

Contact Metal	Relay Operations in Millions	Number of Contacts			Maximum Resistance in Ohms
		In Test	>0.1ω	>1ω	
Pd/Pd	2.5	90	34	29	8.5
No. 1/No. 1	10.0	90	18	10	5.0
No. 3/No. 3	10.5	90	20	13	5.5
22K Au/22K Au	10.0	60	33	27	17.5

These contacts were essentially non-working electrically. However, they did charge the wire to the succeeding contact in the chain to 50-volt potential as they closed and, to this extent, they were electrically working contacts. To determine the effect of this small amount of electrical erosion in carbonizing the polymer, 30 additional contacts in the 22-karat gold test listed above were tested simultaneously without such cable charging, and it was found that only three of these contacts had resistance greater than 0.1 ohm and only one contact exceeded 1 ohm.

The wire-spring relay test results were similar except that a higher percentage failed by high resistance (opens) and a correspondingly lower percentage showed low resistance. The effect of cable-charging closure was to increase the percentage that showed the low-resistance effect, as for the U relays. Also, higher-velocity wire-spring relays had a much greater percentage of contacts with low resistance, again indicating that high impact forces and high slide carbonize the polymer.

6.17 *Noise on Speech Transmission Contacts*

Undesirably high noise levels were encountered in the speech transmission circuits of the No. 5 crossbar system due to deposits of polymer and carbon on the normally-closed palladium contacts of certain relays on the trunk link frame. The noise occurred only when nearby relays released, jarring the frame and causing the contaminated contact to become microphonic. The noise at times sounded to the listener like a banjo twang of such a magnitude that words or even sentences occasionally became unintelligible.

Field tests on U-type relay equipments in service showed that 30 per cent of the noise-producing relays in a large sample would produce noise exceeding 25 db* (just audible). When the contact metal was changed to No. 1 alloy, only 1 per cent of the contacts had objectionable noise. When soft rubber vibration mounts were used with the original contact metal, the number of contacts with audible noise was 5 per cent.

6.18 *Mechanical Wear*

Life tests to determine the mechanical life of 22-karat gold overlay contacts on wire-spring relays indicate a life exceeding 100,000,000 operations. These tests, run with unwired contacts at an accelerated rate, show considerable variation between contacts and between tests with respect to the amount of wear. It is believed that the contacts obtain some lubrication from the products formed from the organic vapors and that, with the slower operating rates that occur in practice, the mechanical life of the gold overlay will exceed the life indicated in these accelerated tests.

Although relays in circuits such as markers and Accounting Center machines may operate a billion times or more during their lifetimes, no trouble is expected with these relays after the gold wears off because of the often-repeated laboratory indication that relays with high operating rates and a history of many operations have low failure rates.

6.19. *Final Tests*

To test the final product, 90 standard AF relays with the gold overlay on the moving contacts were tested in an OCTU, which most closely resembles service conditions. All contacts had been cleaned prior to start of the test, since the present manufacturing process calls for thorough cleaning of the contacts by wet-scrubbing with trichlorethylene.[11] No contact failures occurred in a year's operation of this test. Identical tests made on palladium contacts without gold overlay have had about 60 found open contact failures in this time.

* 25 db above 10^{-12} watts

VII. CONCLUSION

The obvious solution to many of the difficulties experienced with precious metal contacts is to eliminate organic vapors from the contact environment. However, this is often not feasible. The plastics and phenolics used in relay insulation are potent sources of these undesirable vapors, but these insulating materials are desirable for other reasons. Forced ventilation with adequate filtering to remove dust would be uneconomical, as would be the use of activated charcoal to absorb the vapors. For the telephone plant, where so many relays and contacts are used, the best solution would be to make the contacts immune, or at least less susceptible, to the vapors.

Palladium and other platinum-family metals are particularly susceptible to the vapor effects. These metals are suspected of acting as catalysts to form highly insulating films, and no poison has been found which will markedly reduce this effect. The best solution found so far is to overlay the palladium with a gold alloy sufficiently thick to provide for mechanical wear. Where a solid, homogeneous contact without gold overlay is preferred and where the added cost can be justified, Western Electric No. 1 metal can be used and is practically as good. However, although the high resistance effect is eliminated, these gold or gold alloy contacts can still be expected to show the low-resistance phenomenon in the presence of organic vapors. Also, the use of gold does not reduce the heavy erosion that takes place on electrically working contacts in the presence of organic vapors.

Gold overlay on only the moving contacts of wire-spring relays is used for economy and ease of manufacture. The good performance obtained is the result of the decreased polymer formation and the twin contact action coupled with the low persistence of failure characteristic of the polymer. Where the polymer difficulty has occurred on single-contact relays, as in step-by-step systems, no compromise is made and the change to gold alloy (No. 1 metal) is made on both mating contacts.

Preliminary reports from early installations indicate that the contact performance of the new wire-spring relays with gold overlay on the moving contacts will be highly satisfactory.

VIII. ACKNOWLEDGMENTS

The broad investigation of organic vapor contamination of relay contacts was instigated and pursued at the Laboratories largely through the efforts of P. W. Swenson. He also directed the early phases of the relay test program described in this paper.

Research work on the polymer-generating aspects of organic vapors

on contacts was done by H. W. Hermance and T. F. Egan, to whom we are indebted for many stimulating discussions. The effect of contact vibration was discovered and explored by the late C. E. Nelson. The electrical breakdown characteristics of the polymer were investigated by Miss P. M. Hamway. Introduction of the practical results of these tests into relay manufacture was coordinated by H. N. Wagar.

APPENDIX

Simplified Schematic of the OCTM (*Fig.* 18)

When the start key is operated, and later released, the AL relay operates, which in turn operates the ST relay (both these relays remain operated until a contact failure occurs). The operation of the ST relay passes interrupted ground pulses into pulse-dividing relays W and Z. The first ground pulse operates the W relay, which in turn operates

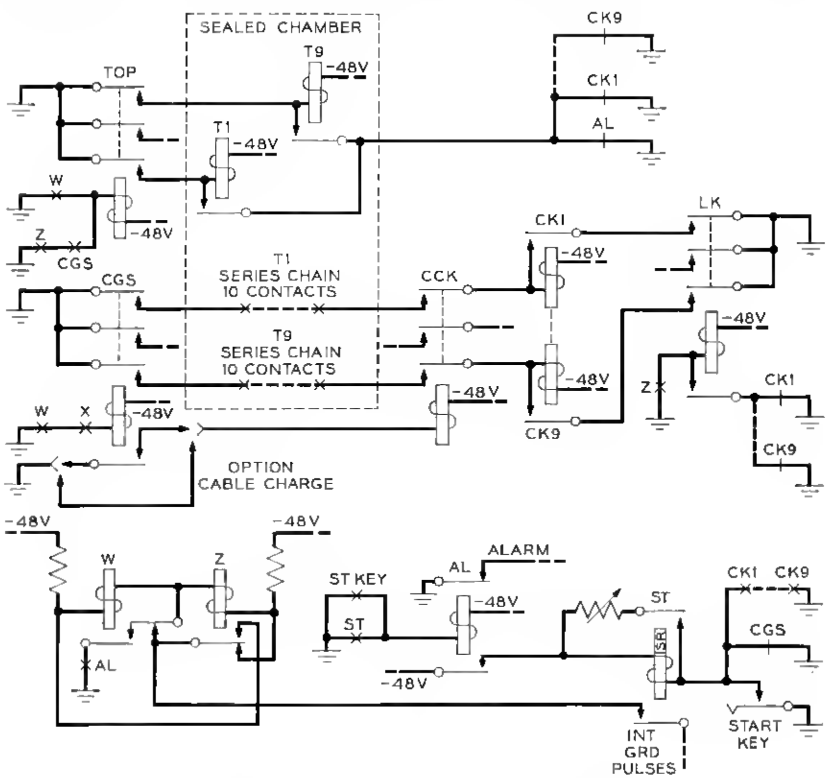


Fig. 18 — Simplified schematic of the OCTM.

the TOP relay, and hence the nine test relays T1 through T9, preparing the contact chains for checking. The first open pulse operates the Z relay, which operates the LK and CGS relays. The CGS relay operates the CCK relay and supplies a ground to the contact chains. If all test contacts are low in resistance, the corresponding check relays CK1 through CK9 operate and lock up, returning the test contacts to ground potential. The second ground pulse releases the W relay, which in turn releases the CGS, which then releases the CCK and TOP relays. The TOP relay releases the T relays. The second open pulse releases the Z relay, which releases the LK relay. The LK relay in turn releases the CK relays, thereby completing the cycle. When a failure occurs on a test contact, a check relay CK will fail to operate. The failure of a check relay allows the ST relay to release, stopping and holding the circuit in the failed position and releasing the alarm relay AL.

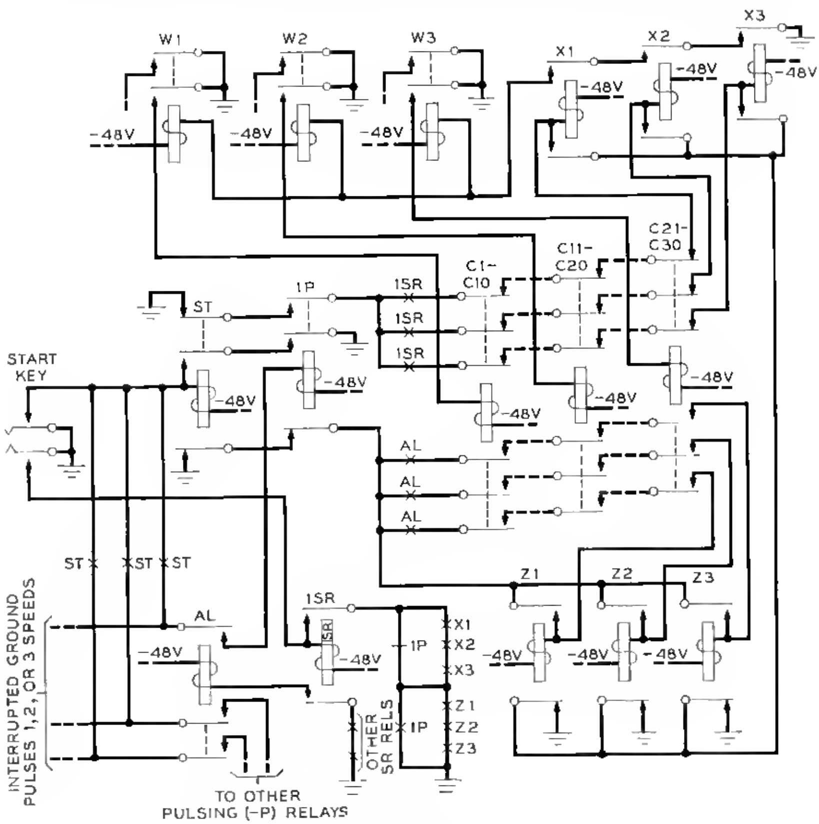


Fig. 19 — Simplified schematic of the OCTU.

Simplified Schematic of the OCTU (Fig. 19)

Approximately one-third of the circuit is shown in the schematic diagram. The operation of the start key operates tbe ST and 1SR relays. The 1SR relay operates the AL relay, which allows interrupted ground pulses to reach the pulsing relay 1P (the AL and 1SR relays remaining operated until a contact failure occurs). The release of the start key allows the ST relay to release when all three interrupted ground pulses simultaneously reach a "no ground" period. (The ST relay remains unoperated during the test.) The first operation of the pulse relay 1P, after the release of the ST relay, supplies a ground to the break-contact series chains of test relays C1 through C30. If all test contacts are low in resistance, the corresponding check relays X1, X2 and X3 operate and lock up, returning the test contacts to ground potential. The operation of all X relays operates the W relays, which in turn operate the C relays. The operation of the C relays prepares the make-contact chains, operating the corresponding check relays Z1, Z2 and Z3, which lock up, returning the test contacts to ground potential. The operation of all Z relays releases the X relays, which in turn release the W relays, and hence the C relays, completing the cycle. When a failure occurs on a test contact, a check relay (either X or Z) will fail to operate. The failure of a check relay allows the 1SR relay to release, stopping and holding the circuit in the failed position and releasing the alarm relay AL.

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